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# Intelligent transport systems in multimodal logistics: A case of role and contribution through wireless vehicular networks in a sea port location ☆

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ABSTRACT

The growing complexity of logistics and its importance as a major economic activity has raised the profile of information and communication technology (ICT) as means to improve the levels of visibility, responsiveness and efficiency in supply chains relying in multimodal transport operations. With the use of wireless vehicular networks, Intelligent Transport Systems (ITS) have the potential to shape the future of multimodal logistics. In the absence of sophisticated ICT tools, the potential role and contribution of ITS and in particular wireless vehicular networks play in logistics is investigated in a multimodal case of a port terminal handling bulk material transported by sea, which is unloaded into haulage vehicles. Event flow mapping and network modelling analysis are used to determine the feasibility of ITS to support real-time data traffic related to the exchange of messages, which are representative of the flow of events taking place in multimodal logistics and which can be associated to high-impact capabilities with economic repercussions such as track and trace.



## 1. Introduction

Logistics has become a major economic activity comprising the process of planning, implementing and controlling the efficient, effective flow and storage of goods, services and related information from point of origin to point of consumption for the purpose of conforming to customer requirements (Council of Logistics Management, 1998). Multimodal logistics has become an important component of logistics worldwide. Hence, in modern deep-sea and short-sea ports, access to other modes of transportation including road, rail, pipeline and air is available. The use of multimodal logistics has been encouraged by government directives and initiatives aiming at making operations more efficient and environmentally friendly. For example, in recent years the European Commission has released a series of calls aiming at the development of short-sea shipping as a sustainable part of the logistics chain as European roads suffer from major congestion problems (DFT, 2007). In Northern Europe, the significance of multimodal logistics can be seen in the growing importance of short-sea shipping comprising regular liner services and ferries operating fast, reliable and flexible connections that carry a wide range of cargos in different types of vessels, including charter vessels for transport of bulk steel and construction materials, between terminals in the region as well as Roll On–Roll Off (Ro–Ro) operations including finished vehicle logistics (DFT, 2007). The efficient management of multimodal logistics would be difficult to achieve without the support of sophisticated information and communication technology (ICT). There is a need of developing electronic logistics management systems, and other applications that can be used to ensure and enhance safety and security and to simplify administrative and customs procedures (DFT, 2007).

In recent years, sea ports have consolidated their position as premier locations for complex logistics networks. For many countries with some of the most developed economies in the world, ports represent their main access gates for trade and commerce, hence ports are ideal transport nodes to investigate the use of innovative ICT to support multimodal logistics operations.

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The characteristic of ports to host different modes of transportation is of significant importance as the combination of specific modes may account for the majority of freight movements in a region. According to the European Commission, in 2005 the total volume of tonnage moved in short-sea shipping was of the order of 591 million tonnes. On the other hand, it is possible that the complexity of multimodal operations can result in serious inefficiencies in logistics. Some examples of inefficiencies associated to the use of road haulage and sea transportation include penalties of thousands of Euros when a vessel has to spend an extra day docked in order to get fully discharged, container lorries missing time slots due to delays for loading a container on a ship, haulage vehicles remaining idle or moving discharged goods to the wrong depot/warehouse within the port.

International logistics requires ICT systems that satisfy a diversity of needs as it has been agreed that international logistics is practically mostly multimodal and involves a number of different players that underline the challenge of implementing information services that work to serve the needs of the whole logistics chain (Leviäkangas et al., 2007). ICT has become an essential part of the rapid and accurate transfer and processing of enormous volumes of data by international transport firms and port organisations (Kia et al., 2000). Indeed, logistics and transportation are totally dependent on ICT as Stefansson (2002) indicates that the flow of information is essential for carrying out an effective and efficient movement of consignments and using more advanced technology and data sharing it is possible to increase the resource utilisation and thus reduce costs. Despite the wide recognition of the importance of ICT in logistics and transportation, Ngai et al. (2008) highlights that little empirical research has been conducted to study the use of information technology applications to support logistics operations. Furthermore, it is expected that emergent technologies may also have a significant impact on already complex multimodal logistics. This is particularly important as Kengpol and Tuominen (2006) highlight that new technologies have affected the practice and significance of logistics management. For example, Dullaert et al. (2009) work on multimodal transportation involving the combined used of road transport and inland navigation recognise the need for a communications platform to make possible the integration and sharing of operational information in the supply chain and to mitigate problems such as low reliability and quality of mobile data connections. The solution envisaged by them comprised a real-time decision support system in which intelligent software agents handle communicative tasks, exchange desired amounts of information among different users using common exchange protocols, which act as translators between different systems.

In order to cope with the strategic importance of ports, significant investments in ICT have been taking place in recent years. For example, ports are now becoming more technologically advanced with the adoption of ICT such as GPS systems aboard gantry cranes, ICT support for quay planning, routing of automated guided vehicles as well as equipment used for stacking of containers and invoicing (Neade, 2008). But the attention to ports using ICT is not recent. For example Kia et al. (2000) investigated the importance of information technology and its role in improving cargo handling operational systems. They used a simulation model to compare the productivity of a container terminal equipped with electronic devices against a terminal without such devices. The results of the simulation provided evidence that helped to explain why container tracking systems are given high priority among operational computer applications in ports.

ICT technologies including RFID, GPS-enabled devices, Cellular Networks, 3G and Wi-Fi have provided enhanced levels of visibility and connectivity for multimodal logistics. For example, RFID has received significant attention by academics and practitioners and several studies on RFID applications can be found in the literature with particular emphasis on enhancing track and trace capabilities. The work from Zhou (2009) highlights that reasons why track and trace capabilities have become so important can be linked to the fact that for many organisations, it is becoming increasingly critical to know the status of an item instantaneously, as well as knowing the processes it has gone through and the history of transactions involved. The instantaneous status of an item includes identity, precise location, physical status and other key features. On the other hand the use of heterogeneous technologies can represent a burden to business applications relying on them mainly because of problems related to reliability, connectivity, limited range, scalability and security.

An element that has the potential to significantly shape the future of multimodal logistics and in particular sea port operations is Intelligent Transport Systems (ITS). In fact ITS have become the next big initiative for the management of transportation in Europe and other parts of the world. The ERTICO research project (2007) encapsulated the concept of ITS as the use of advanced ICT to achieve a reduction of congestion and accidents while making transport networks more secure by reducing their impact on the environment. Zomer and Anten (2008) highlight that ITS relate to important challenges for improved global supply chain design and operation, including real time control, based on real-time data, which ultimately affects risk and resiliency.

Among the various technologies used to support ITS, wireless vehicle networks represent a fundamental component, which will influence future transportation and logistics operations. Akaiwa (1997) states that the growing importance of wireless vehicular networks can be directly associated to the popularity and growth of mobile wireless communications, where advancements in wireless channel modelling techniques and the subsequent development of sophisticated digital transmission methods make possible to provide high data rate communications whilst adhering to stringent Quality of Service (QoS) requirements.

The growing complexity of multimodal logistics operations in ports and in particular the interdependencies between sea transportation and road haulage represents a strong case for exploring the efficient use of information and communication technology (ICT). In particular technologies, which are key components of ITS, such as wireless vehicular networks, which can impact the supply chain needs more attention.

In the following sections we review the developments of ITS, the nature of port operations and the potential effect of ITS on multimodal operations. The objectives and research methodology used are discussed followed by the analysis of an industrial case study used to illustrate the role and contribution of ITS to multimodal logistics through wireless vehicular networks in the form of Dedicated Short Range Communication (DSRC). The case addressed involves examining in detail tipping operations of bulk material in a port terminal using event flow, mapping and network simulation to demonstrate the feasibility of wireless vehicular networks to support data traffic, which is representative of track and trace capabilities needed in complex multimodal logistics operations such as those taking place in sea ports.

## 2. Intelligent transport systems (ITS), wireless vehicular networks and the potential to affect multimodal operations

In recent years, ITS have emerged as an initiative that will not only transform transportation by enabling Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications but also the overall efficiency of logistics operations. In fact, it has been recognised that in logistics, ITS play an important role in achieving paperless information flows; however, the crucial role that ITS play in achieving reliable, flexible, green, sustainable, safe and secure logistics has not been fully researched (Zomer and Anten, 2008). Current and upcoming European freight transport action plans do not fully recognise the unique and crucial role ITS plays in logistics (Zomer and Anten, 2008), as most of the present research on ITS has focused on traffic control, incident detection and accident prevention.

ITS relying on wireless vehicular networks have the potential to become the platform that overcomes problems related to technology proliferation like reliability, connectivity, limited range, scalability and security. This is important as according to Shanbaq (2007) modern companies are experiencing data overload as a consequence of using many disparate new technologies and are seeking a unified operating picture for situational awareness.

In recent years academic and practitioners in the field of transportation have started to address the importance of wireless vehicular networks. For example, Mobile Adhoc Networks comprise the intelligent infrastructure required to enable vehicles communicate with other vehicles near them as well the infrastructure to deliver intelligent control and safety applications and location-based services (Blythe, 2005). Jiang and Delgrossi (2008) emphasise that vehicular environments impose a set of new requirements on today's wireless communication systems. It has been highlighted that vehicular safety communications applications cannot tolerate long connection establishment delays before being enabled to communicate with other vehicles encountered on the road. Similarly, non-safety applications also demand an efficient connection setup with roadside stations providing services. In the future terminal operators and road haulage companies will benefit from services available in such networks to make more efficient handling cargo inside a port.

In the ITS context, Dedicated Short Range Communication (DSRC) at 5.9 GHz promises to become a reliable wireless vehicular network platform to support road safety needs but also non-safety applications such as those required in logistics operations. DSRC is based in the IEEE 802.11p standard, designed to handle different types of service applications, including the transmission of both safety and non-safety messages into two modalities: V2V and V2I.

Regarding the considerations for setting a wireless vehicular network, in DSRC there are two types of messages transmitted: Wireless Access for Vehicular Environment (WAVE) Short Messages (WSM) and IPv6 traffic. WSM messages involves low latency and critical safety-related messages assuming a real-time propagation while IPv6 traffic is generally related to commercial services such as download or streaming of data. To allow Internet Protocol (IP) traffic, the discovery of IP addresses (WAVE, 2005) is performed by generating a global IP address with the Media Access Control (MAC) address and the IP prefix advertised by the current roadside infrastructure (Farradyne, 2005). A timer value is assigned to this IP address so when the timer expires, the IP address is no longer valid. If the vehicle attaches itself to a new roadside infrastructure, a new IP address based on the new IP prefix must be generated.

DSRC has been developed to provide high-quality roadside-vehicle communication services for intelligent highways (Cai and Lin, 2008). The deployment of this technology could address several needs including seamless information exchange, security and integrity of information exchanged or the capacity to forecast accurate travel times (Nyquist and Bergsten, 2008). It has been documented that DSCR is a technology that offers better performance than cellular and satellite systems for most important applications found in the market comprising probe data, mileage user fees, signage, tolls, traffic data and V2V safety (Marousek et al., 2008).

The hardware components of a DSRC vehicle network operating at 5.9 GHz, fundamental for developing the logistics capabilities of ITS, include On-Board Units (OBUs), Roadside Units (RSUs) and Message Switches. Other components include Network Management Units, Certification Authorities and Map Servers. An On-Board Unit (OBU) comprises a hardware module installed within the vehicle, which includes a 5.9 GHz DSRC transceiver, a GPS location system, a processor for application services and a human machine interface (HMI). A wide range of applications generated at the OBU can be formatted as IP traffic and propagated using an available DSRC service channel. The Road Side Unit (RSU) is considered to be the gateway between the fixed infrastructure and vehicles. RSUs comprise a DSRC transceiver, a GPS location system, an application processor and a router that is attached to the fixed network. RSUs comprise roadway, toll collection, parking management and commercial vehicle check. The RSU periodically broadcasts advertisement messages within its radio transmission range to make neighbouring vehicles aware of its presence. The function of the message switch is to handle and parse all the data intended to reach any network element. It also performs message management and subscription operations according to the message's priority for efficient bandwidth distribution.

Currently DSRC technology is commercially utilised in electronic toll collection (etc) applications (Cai and Lin, 2008). Another use of DSRC technology includes building-up seamless roadside communications systems, as it can be used for mobile information transmission (Cai and Lin, 2008). Road safety has been seen as a major use of DSRC. The European Union (EU) has set an ambitious traffic fatality reduction goal. According to Alexander and Ippoliti (2007) if the EU concludes that DSRC technology could contribute significantly to that goal, then it is likely that financial or legislative incentives might be released to deploy the necessary infrastructure. Under the sponsorship of national governments DSRC can become the next platform to enable ITS through the exchange of information between vehicles and road side infrastructure.

Given the wide implications of ITS, in recent times, researchers and practitioners have started to investigate the economic implications and benefits of ITS and wireless vehicular networks. Kim and Kang (2007) state that providing real time traffic information is a key for effective implementation of ITS. For this reason they focused on the economic evaluation of recent technological trends involving DSRC applications for ITS in Korea's City Bus Information System (CBIS) and ETC Systems. Regarding the study of the socio-economic impact of ITS, Juan et al. (2006) introduced a case study to demonstrate the use of data envelopment analysis to analyse the socio-economic impact of convoy driving systems when cost-benefit analysis is the dominant method for evaluating ITS and other transport engineering projects.

The continuous growth in the adoption of vehicle telematics and communications solutions can be a major catalyst in widening the adoption of ITS services based on DSRC wireless vehicular network technology. At present there are about 700,000 commercial telematics subscribers in Europe and this may reach to over 1.7 million by 2012 (Marousek et al., 2008). It is expected that revenue for commercial telematics services will rise to US$900 million in 2012, from a 2006 level of US$412 million (Practel, 2008).

Security is also an element that has been evaluated when considering the deployment of wireless vehicular networks in locations such as ports. Coronado Mondragon et al. (2009) addressed the modelling of secure access architectures when investigating the feasibility of using a wireless vehicular network in a multimodal logistics environment as means of providing enhanced visibility and connectivity. This is important as the deployment of next generation wireless vehicular networks require secure access architectures to provide a high degree of security.

Sea ports represent sites, which can receive a major impact from wireless vehicular networks as sea ports carry out complex logistics operations. Modern sea ports may comprise areas of several thousand square metres with berths long enough to receive large vessels carrying all sort of goods. For example, the Port of Hong Kong—Kwai Tsing Container Terminal—has a berth length of 5000 m, space for 14 berths and a total area of 1.4 million square metres. The complexity of operations undertaken at Kwai Tsing Container Terminal has motivated the adoption of sophisticated ICT solutions to guarantee the high performance of all operations undertaken in the terminal.

Another element why technology such as DSRC could be adopted in major port operations is the emerging importance of portentric operations and logistics. According to Neade (2008) portcentric is seen as a way to rationalise the supply chain by driving down the delivery costs per unit. In portcentric operations it is expected that road hauliers, port/terminal operators and shipping companies rely on ICT at different levels. However, ports operate in a multi-faceted environment, which has been rated as inadequate and characterised by delayed information exchanges (Nyquist and Bergsten, 2008). Moreover, according to Portcentric Logistics (2009), ports have traditionally been seen merely as points at which the transport mode changes from sea to road or rail. Ports are also viewed as a source of additional cost within the supply chain, a bit of a 'black-hole', which swallows-up cash for quay rent and other idiosyncratic items like 'Lo–Lo' (Lift on–Lift off) charges (Portcentric Logistics, 2009). In the UK, some ports are actively encouraging companies to locate distribution centres at ports rather than in their traditional locations, which tend to be in geographically central, inland locations. They argue that current patterns of (inland) distribution centre location ignore the fact that most of the freight that passes through these distribution centres first has to go through a port (Mangan et al., 2008). DSCR can affect key facilities in a port such as electronic logistics management systems, facilities to ensure and enhance safety and security, facilities to simplify administrative and customs procedures. Overall, for transport systems in a sea port wireless vehicle networks such as DSRC have the potential to become the background infrastructure where different multimodal logistics players can exchange data like as shown in Fig. 1.

The adoption of ITS services running on wireless vehicular networks such as DSRC has great potential given the inherent characteristics of the road haulage industry. For example, in Europe trucking is predominantly short-haul (Practel, 2008) with most hauliers moving cargo within their own national borders (InnovITS, 2008). This situation observed in Europe describes perfectly the use of road haulage around ports (short-haul).

The next section presents the objectives and methodology followed to test the feasibility of deploying wireless vehicular networks—DSRC within the working conditions of a modern port.


**Fig. 1.** DSRC as the platform that can be used to support data exchange among different users of the port.

The results are discussed followed by recommendations and conclusions.

## 3. Research methodology

In the previous sections we have provided arguments to support the idea of deploying an ITS-related wireless vehicular network in the form of DSRC to assist in multimodal logistics involving road haulage and sea transportation commonly found in sea ports. Next, we need to explore how feasible it is for DSRC-based wireless vehicular networks to support the needs of multimodal logistics found in ports. Hence, the objective of this work is to use a number of tools to test the feasibility of ITS to support real-time data traffic related to the exchange of messages, which are representative of the flow of events taking place in multimodal logistics and which can be associated to high-impact capabilities with economic repercussions such as track and trace. This will assist us to identify the role and contribution of ITS through wireless vehicular networks to multimodal logistics taking place in sea port facilities.

In order to meet the objective of this work, the methodology employed incorporates a case study supported by the use of process mapping and modelling/simulation. The methodology employed in case-study research has been thoroughly explained by Yin (1994). Generally, the case-study has some longitudinal dimension since it is conducted over a period of time. A ramification of case-study is the site visit, which was also used in this study. Seaman (1999) provides a detailed description of the use of a site visit in research. According to her, a site visit is planned to obtain first-hand information from tours of specific facilities and services, interviews with individuals or groups, or observations of specific activities at the site. In addition, the site visit can be used to obtain reports, brochures, and examples of products or services made available at the site. Site visits provide the opportunity to obtain first-hand information about users or activities in a particular setting. Another benefit is the ability to evolve the data collection strategies on site, depending on the topics the evaluator determines are important to probe for additional information (Seaman, 1999).

Important components of the case study methodology adopted for this research are the use of process mapping and modelling and simulation. Process mapping as employed in this work comprises the use of rich picture techniques as used by Roh et al. (2007) and a multi-stage information flow mapping. On the one hand rich picture facilitates the understanding of the role of sub-systems in port logistics process (Roh et al., 2007), whilst information flow mapping relates to the characteristics of a specific business process. Moreover, mapping has been embraced in ITS research and examples include fulfilling information needs by mapping information systems into service architectures (Leviäkangas et al., 2007). These two approaches emphasise information and material flow, as in value stream mapping. The use of value stream mapping in logistics/supply chain management analysis can be found in Coronado and Lyons (2008).

In this work process mapping is followed by the use of network modelling to model the elements comprising the topology of the wireless network that will be supporting multimodal operations in a sea port. Modelling and simulation have been widely used in the analysis of multimodal transportation. Parola and Sciomachen (2005) acknowledge that discrete event simulation models are commonly used for capturing the synchronisation processes between the handling resources and the arrivals and departures of vessels, trains and trucks, since the complexity of resource allocation rules and the variety of stochastic processes involved make almost impossible the use of analytical approaches. They address how to face the impact of sea traffic growth on land infrastructures involving the degree of saturation of railway lines and the level of congestion of truck gates. In this work modelling enables the possibility to investigate the most important characteristic of a wireless vehicular network in multimodal logistics: the reliable data transfer between vehicles and road side units. Network modelling is used to illustrate the potential of a wireless vehicular network configuration of handling increased volumes of data traffic with minimum degradation levels, which is critical to maintain high levels of track and trace capabilities. Additionally, it is possible to analyse the system performance when multiple users try to request network access concurrently.

Considerations for the deployment of wireless vehicular networks such as DSRC in multimodal logistics are based on the recognition that "logistics, in particular distribution, faces an static environment as well as dynamic environment, and a complete logistics distribution system not only needs static data but also real-time dynamic knowledge to carry on real-time intelligent scheduling, dynamic routing planning and so on" (Liu et al., 2006). We believe the approach followed in the case presented in this paper is relevant as research on ITS and wireless vehicular networks has concentrated mainly on vehicular safety communications applications and little on investigating multimodal logistics. In the particular case of DSRC, the primary goal has been to enable public safety applications that can save lives and improve traffic flow (Jiang and Delgrossi, 2008).

Track and trace of haulage operations can have a major impact on haulage operations in a sea port. In sea ports haulage operations have their very own particularities, for example, containers/ trailers emphasise eliminating/reducing idle time associated with loading/ unloading a container box, hence the need to make sure trucks leave the terminal premises in a short period of time. Unloading/loading solid bulk material represents a complex activity that requires dedicated resources in order to complete the task in the most efficient way. For example, unloading bulk materials such as coal, fertilizers or biomass requires allocating a number of haulage vehicles that will move material from the tipping point to bulk material depots likely to be located within the geographic confinements of the port. However, because of the volumes of bulk material transported by vessels (e.g. 50,000 t) several trucks need to be allocated to an unloading operation. Of all logistics operations carried out in a port, bulk operations can receive a major upgrade from the adoption of wireless vehicular networks as it appears that major technological developments involving ports have addressed mainly container operations.

The case presented here is based on the operations taking place in one of the four ports comprising the Humber region in North East England. These ports handle commodities of a diverse nature including bulk and forest products, fresh produce and perishables, general cargo, minerals and ores, steel and other metals, also Ro–Ro (roll-on/roll-off, e.g. finished vehicles logistics), containers and liquid bulks.

During a period of 10 months several visits to the site including five interview sessions with managers in the Operations and ICT departments, as well data collection and access to data sets took place in order to have a detailed understanding of the operations carried out on the site, as well as to identify the information needs of multimodal logistics.

A practical example where a wireless vehicular network could be deployed is in the allocation of trucks to tipping operations involving dry bulk materials from a vessel docked in a given berth (point of discharge) to a number of depots/ warehouses (open or closed) within the port. The particularities of the use of road haulage in unloading operations of bulk material carried by small, medium and large vessels suggest that the adoption of technologies such as wireless vehicular networks would enable different applications used by road hauliers, shipping lines and terminal operators to get and send real-time data from/to haulage vehicles. In Fig. 2, specific information systems applications such as daily operation plans or haulage unloading control could use DSRC to know the exact location of bulk material road hauliers.

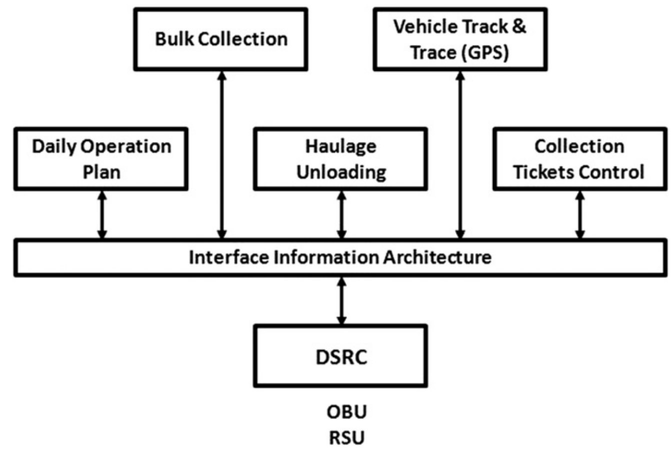


**Fig. 2.** DSRC becoming the platform that links vehicles and enterprise applications.

The bulk terminal investigated is a deep-water location with 300 m long berth where ships are unloaded or loaded by the terminal's mobile quay cranes. Additional bulk handling capabilities are available at the terminal's enclosed dock with a total 198 m long berth and with the capacity to handle vessels of a maximum DTW of 38,000. As part of the services available general quayside warehousing is available representing a total of 30,000 $m^2$ of high-quality bulk general purpose warehousing and extensive open storage.

## 4. Mapping and information requirements of bulk material handling

The identification of logistical processes through mapping is a key activity in the deployment of ITS through DSRC-based wireless vehicular network within a port. A mapping activity requires the involvement of players such as road hauliers and port/ terminal operators. Mapping has the purpose of identifying the flow of information and the flow of material. But in particular, mapping the flow of information involves identifying information needs as well as identifying the capabilities required of information exchange between vehicles and RSUs, and the possibility of updating enterprise systems of different players in the supply chain with the resulting increase in visibility levels.

The best way to test the feasibility of deploying ITS through wireless vehicular network technology is to actually get involved with a port terminal operator and investigate the current state of the use of ICT to support running multimodal logistics operations. Fig. 3 shows a rich picture diagram for the tipping of bulk material using road haulage vehicles.

As a vessel approaches the port, the information regarding cargo documentation is transmitted to the terminal operator, which is responsible for selecting the docking berth for the vessel to be unloaded, checking the availability of cranes and other tipping equipment and allocating trucks from a group of 20 internal road haulage companies. The terminal operator generates a spreadsheet with details containing date, contract, day, operation destination and time. Details are passed to the weighbridge controller who tells a truck where, of the available sites, to go to unload its bulk cargo. In case a mistake is identified during

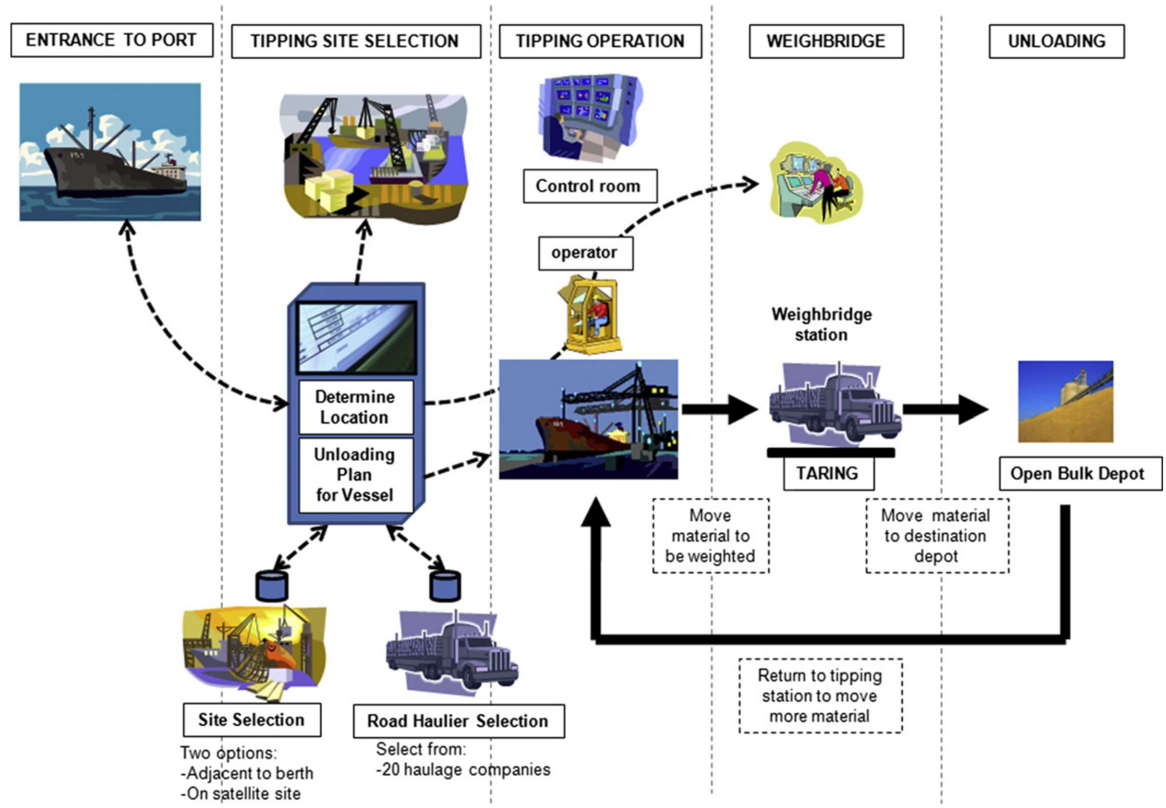


**Fig. 3.** Rich picture for tipping of bulk material in port operations.

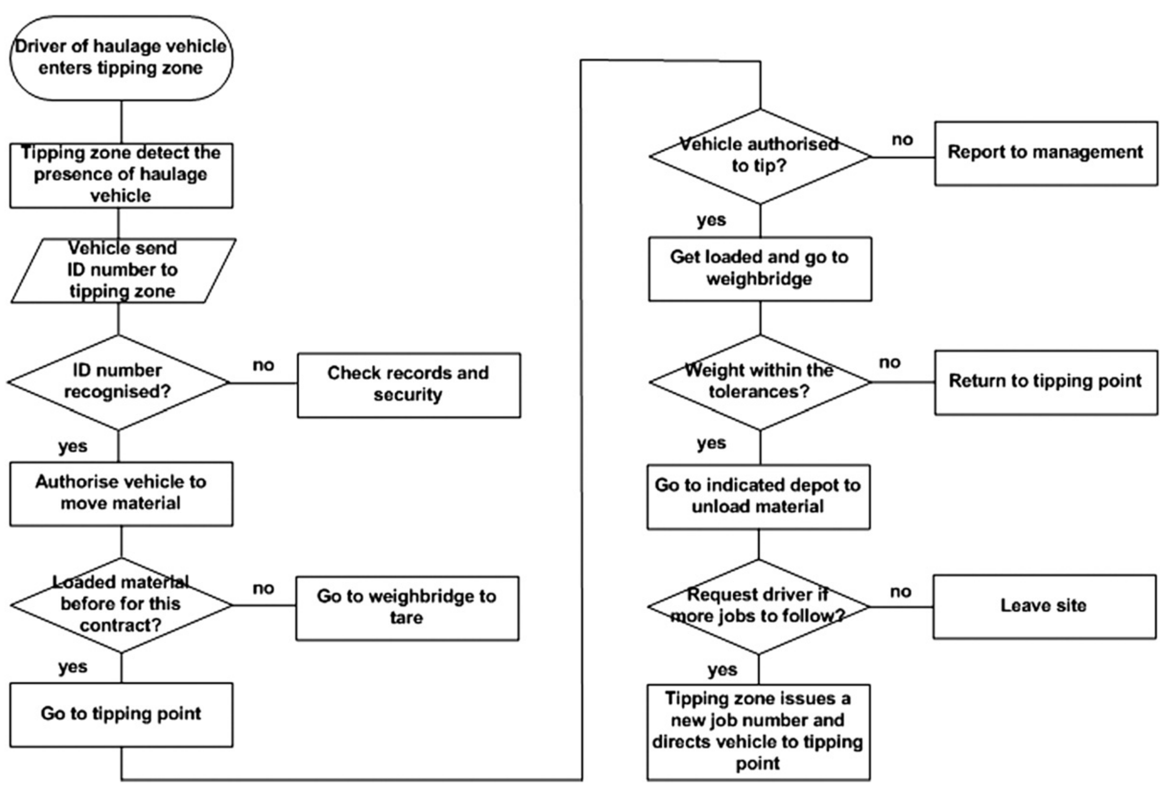


**Fig. 4.** Decision flow diagram for tipping bulk material in a port.

weighing – taring – a truck is asked to return with its cargo to the tipping point to solve the error. After returning to the tipping point, the truck has to go back to the weighbridge to weigh in and receive unloading instructions.

In Fig. 3 the cycle of loading a truck, weighing – taring – discharging goods and returning to collect a new load normally takes 20 min. Materials handled can include coal, animal feed, fertilisers but also hazardous materials, which demand close track

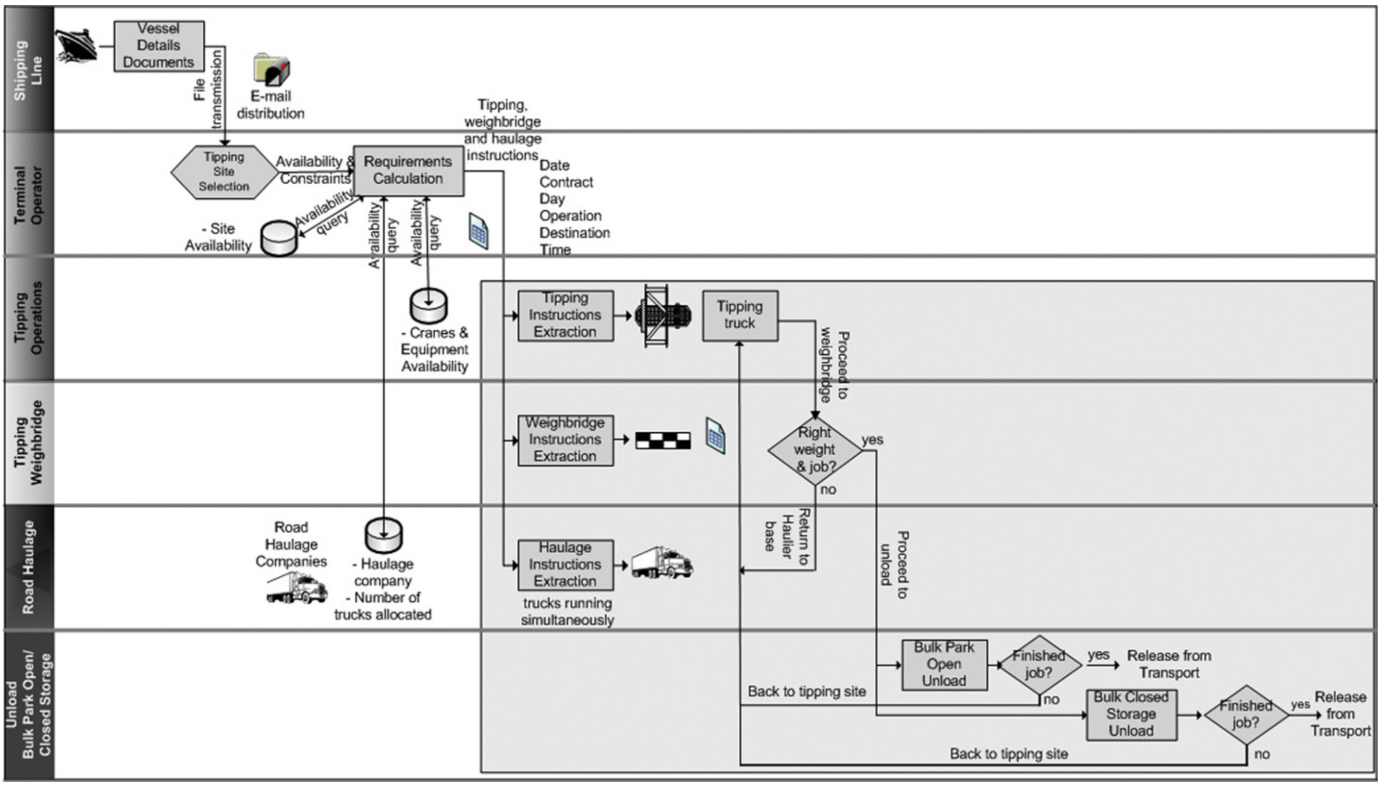


**Fig. 5.** Multi-layer map associated to the process of tipping bulk material.

and trace that can be achieved with wireless vehicular networks and its IP capabilities. Fig. 4 shows a decision flow diagram representing the logic behind the use of trucks to unload bulk material, from a vessel to a specific depot within the geographic confinements of the port.

A multi-layer map of the process associated to the tipping of bulk material is shown in Fig. 5. Layers included in the representation of information and material flows include the shipping line, the terminal operator, which is in charge of tipping operations, the weighbridge station, which verifies the product moved, the haulage companies and the depots where material is unloaded.

The current state of ICT capabilities available to the terminal operator comprises the use of an Excel spreadsheet called shipping plan. For a vessel to be unloaded, this plan shows the agreed unloading plan with holds emptied and cleaned as well as key details such as weight and times. Additionally, the shipping plan requires an extra spreadsheet showing the number of trucks from haulage companies allocated to an unloading plan as well as details already mentioned such as date, contract, day, operation destination and time.

Present haulage operations involve a high degree of manual intervention as instructions in paper are given to truck drivers about the various depots they have to take their bulk load. There are no means available to know if truck drivers are following the instructions given and delivering their bulk load to the specified depot. Some customers of certain bulk materials such as biomass demand constant monitoring of an unloading operation. Given the conditions mentioned above the whole operation is susceptible to error, as drivers may end up transporting a bulk load to the incorrect depot/site. In the port operations observed there were three different open deposits for bulk products and one bulk covered warehouse. It is evident visibility of moving material is absent from the current state of operations.

The lack of a technology and support applications that can be used for real-time track and trace can have several economic implications. Mistakes associated to the incorrect dumping of bulk material in wrong sites may result in delays to vessel departures. Another implication is the inability to provide accurate billing to customers. A key implication is the need for real-time updates and accuracy on truck drivers and operators payments (truck drivers are paid by tonnage moved). Other implications of having ITS through a wireless vehicle network supporting haulage operations in a sea port include the possibility to have an accurate register of haulage traffic entering and moving within the port premises as well as for highway code enforcement.

**Table 1**
Road haulage tipping of bulk material requirements.

| Notation | Description |
|---|---|
| Dt | Date |
| Ct | Contract |
| Dy | Day |
| Op | Operation |
| Tm | Time |
| Tn | Tonnage moved |
| Od | Operator identifier |
| Ri | Road hauler identifier |
| Cp | Current position |

Bulk tipping is an operation that can benefit from the capability to provide real time track and trace hence the challenge to have a network robust enough to support the data traffic associated to the continuous exchange of messages between the haulage vehicles and the road side units within the port. The information requirements that need to be transmitted to support tipping operations are depicted in Table 1. The schema represented in Table 1 constitutes a basic structure, which can be used to monitor the flow of vehicles moving bulk cargo within the confinements of the port.

The identification of requirements is necessary to set guidelines regarding the description of information and the size of files exchanged, the frequency of updates plus the capacity of the network to handle data traffic. The particularities of the tipping of bulk material process include: a contract number, which is unique to the vessel to be unloaded and to the bulk material handled; up-to six vessels carrying bulk material can be docked and unloaded at any given time and several haulage vehicles can be allocated to a contract number involving unloading operations. Limitations that can take place during the tipping of bulk material include trucks remaining idle for long periods of time and restricted monitoring capabilities of material moved.

## 5. Simulation and application of wireless vehicular networks in support of bulk materials handling

The purpose of the wireless vehicular network is to enable data traffic associated with the exchange of messages between haulage vehicles and road side units as representative of track and trace capabilities required in the port. The model proposed in this simulation takes into consideration the IPV6 traffic capabilities of wireless vehicular networks like DSRC.

The network simulation makes possible to demonstrate the effects when mobile nodes exchange data with the port server (hosting an application) through roadside units. Fig. 6 shows the proposed network superimposed over the map of the port terminal with the area covered approximately 1.5 miles long by 1 mile wide. It is important to note here that DSRC is expected to provide coverage over a range of up to 1000 m (NHTSA, 2005). The proposed network is comprised by four WLAN access points connected through an IP cloud, which represents the core of the network. The four routers set in the configuration are of the WLAN Ethernet type.

The mobile nodes in this case represent haulage trucks used in the tipping of bulk material. The nodes are of the wireless LAN workstation type. In an initial trial only one truck was included in the simulation, and then followed by 10, 20 and 30 trucks. Mobile nodes use defined trajectories to roam through all four access points in the network. The network supports reliable data transfer between haulage vehicles (deploying onboard units—OBU) and the port server (reliable data transfer between a remote workstation and the centralised data repository).

A simple tipping configuration consisting of one tipping crane, one weighbridge location and one open bulk depot has been considered for the simulation and application of wireless vehicular networks in support of bulk materials handling. Using this simple configuration it is possible to have up to a maximum of 10 trucks allocated to a tipping operation without experiencing physical bottlenecks during the process. In this scenario the tipping of bulk material cycle for a truck is 20 min.

Apart from the network configuration chosen for simulating data transfers related to the tipping of bulk material, a key component required relates to the design of an application/service to estimate the total average response time while considering the processing time at each tier process. OPNET® (2009) Application Characterisation Environment (ACE®) whiteboard tool was used to assemble the application/service. Within a simulation networking environment, the ACE® whiteboard is a valuable tool fit to assess the behaviour of different tier processes. The intention of using an analysis module such as ACE® is to provide the necessary tools to analyse the performance of a whole communication process by simulating an application tier flow within the deployed network topology.

For the purpose of the simulation work, it is assumed that the data that needs to be exchanged between the OBU inside the haulage vehicle and the RSUs where data flow to/from the port server is about the same size (bytes) as the records that include the fields stated in Table 1 (date, contract, days, operation,

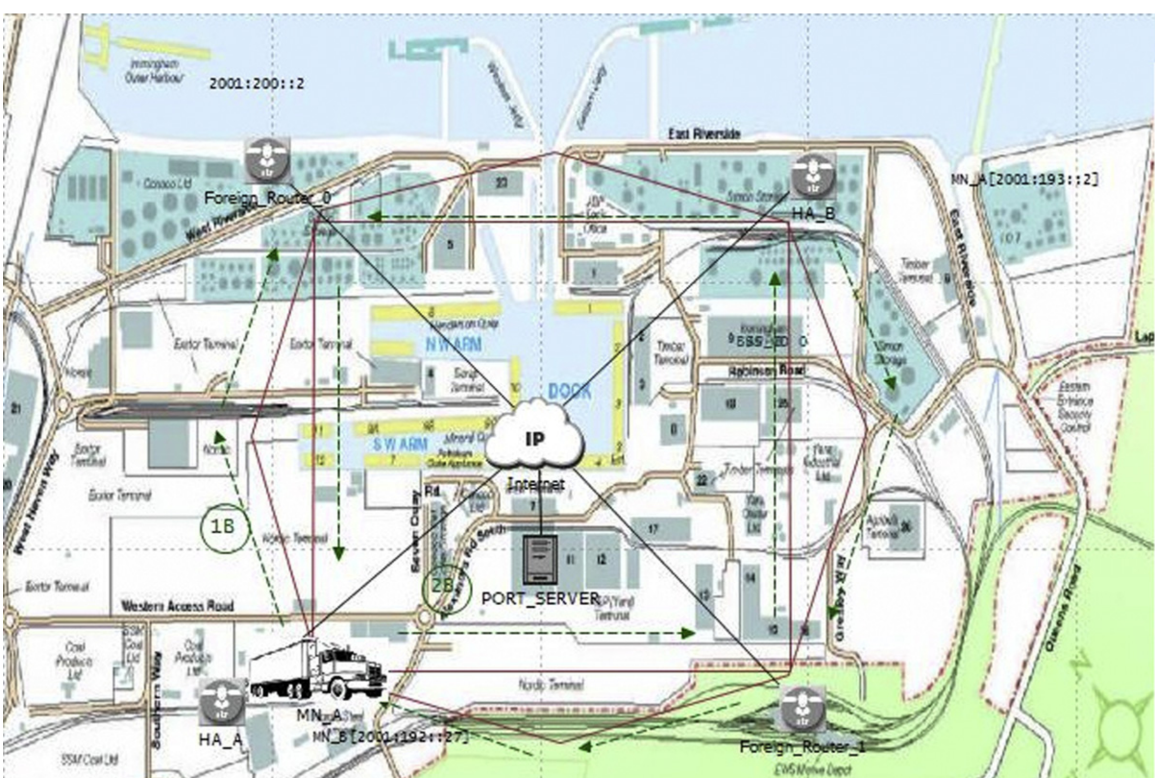


**Fig. 6.** Layout of the simulated DSRC-based network.

destination, time, tonnage moved, operator identifier, road haulier id and current position). An ACE® process lasting 0.455 s is used to illustrate the potential of the above wireless configuration of handling increased volumes of data traffic with minimum degradation levels, which is critical to maintain high levels of key ITS properties such as track and trace capabilities. Assumptions for the simulations included vehicles (trucks/mobile nodes) travelling at low speeds (30 mph) and which is the speed limit within the port premises. The results of the associated response time for 1, 10, 20 and 30 trucks are presented in Fig. 7. Reasons for an increase in vehicles include serving a large vessel or more ships docked in short distance from each other.

The application response time shown in Fig. 7 is the round trip time it takes for a message originated in the vehicle destined to the application server. The exchange of messages is represented as an ACE® tier process from the origin to the destination and which is deployed in the network topology as defined in the OPNET® Wireless Modeller Suite project editor. Mobile IP protocol was adopted for the simulations. If one truck is being employed, the application response time associated equals 1.5 s. If 10 trucks are allocated within the first five minutes of the simulation time, the response time goes up to 3.6 s, before stabilising to less than 2 s after 15 min of simulation time. If 20 trucks happen to be allocated to a tipping job and running the web service application, the application response time experienced would be in the order of 4 s, before stabilising to 2.3 s after 15 min of simulation time. When the total number of trucks employed increases to 30 trucks the initial application response time climbs to 4.6 s within the first 5 s of simulation time and after that it starts to stabilise until it reaches a response time of 2.7 s.

An important aspect to highlight here is that although the length of the simulation period was one hour, the results show that the application response time stabilises in the first 15 min of starting a job and the difference between running one truck or 30 will be a delay of 1.2 s (see the tails of the graphs shown in Fig. 8).

The results of the simulation of the data traffic for the proposed network involving trucks allocated to tipping jobs are shown in Fig. 8. Messages are short in size, have a period of repetition of 30 s and are not considered stream applications.

The results of the data traffic flow analysis/simulation show that the traffic associated to a single vehicle is stable at all times at less than 500 bytes/s. If 10 trucks are doing a job, the expected data traffic obtained is in the order of 2.5 Kbytes/s. The corresponding data traffic for 20 trucks is 5Kbytes/sec and for 30 trucks is 7.5 Kbytes/s. In the cases for 10, 20 and 30 trucks it was possible to observe that there were high volumes of data traffic levels at the beginning of the simulation but those levels stabilised within the first five minutes.

The results show that ITS through a wireless vehicular network technology such as DSRC, which has received attention in terms of being used to reduce traffic accidents and road congestion, has the potential to be used to support multimodal logistics,

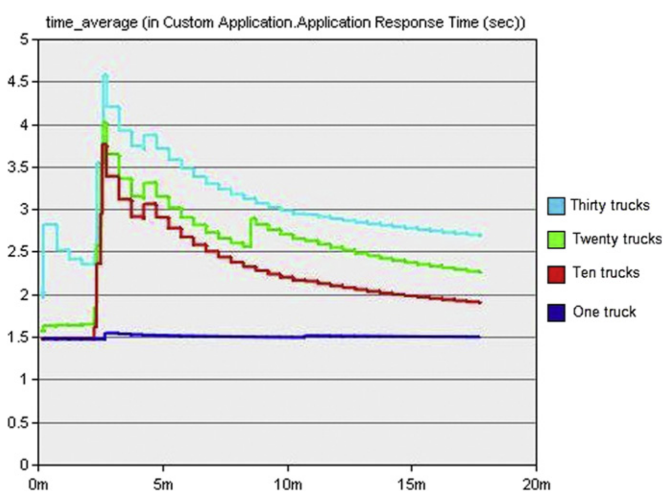


**Fig. 7.** Application response time for 1, 10, 20 and 30 trucks.

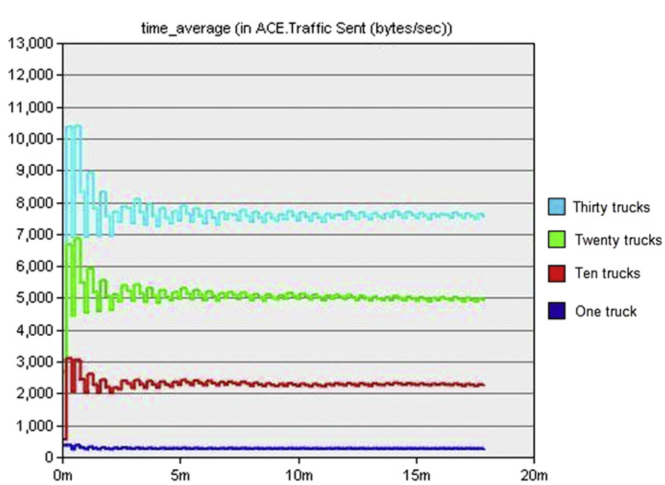


**Fig. 8.** Application traffic flow for 1, 10, 20 and 30 trucks.

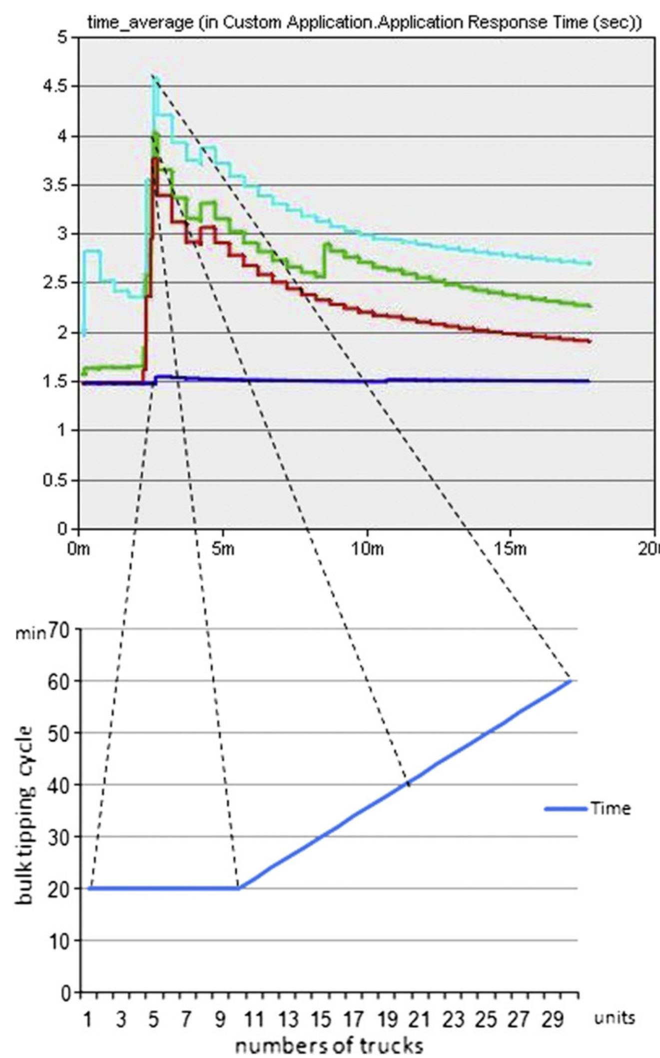


**Fig. 9.** Increases in bulk tipping cycles from 1 to 30 trucks.

especially in port site operations that require haulage trucks allocated to job contracts that can last for many hours or the time needed to unload a vessel carrying bulk material. The delays of 2.7 s are adequate, given the size of the area covered.

Although tipping of bulk material is a manual-intensive activity, still the use of sophisticated information systems can provide detailed monitoring capabilities to avoid costly mistakes such as materials taken to the wrong destination, weighbridge instructing vehicles to return to tipping position because of wrong instructions or handling of hazardous materials to mention just three examples.

Demonstrated that a wireless vehicular network might be capable of handling the data traffic related to increases in the use of trucks allocated to tipping operations, the main physical constraint is actually represented by the capacity of the crane used in the tipping of bulk material and to a lesser degree the capacity for checking weight (taring) and unloading material. In the simple bulk tipping configuration considered in this work, delays start to occur when more than 10 trucks are used in the unloading operation. In this case delays of two minutes start to occur for every truck added to the bulk tipping operation. Hence, for 20 trucks the bulk material cycle reaches 40 min and for 30 trucks the bulk material cycle reaches 60 min. Fig. 9 depicts both the increase in the cycle of tipping bulk material if the number of trucks allocated to a tipping operation goes up and the previously presented response time experienced by the wireless vehicular network for handling 10, 20 and 30 trucks.

The graph shown in Fig. 9 is relevant as haulage trucks associated to bulk tipping share the roads with other vehicles. Hence it is important that the wireless vehicular network is capable of handling high data traffic levels for the needs of all road users.

## 6. Further research

Further research work is required for investigating different ways to optimise the number of elements comprising the wireless vehicular network used to support multimodal logistics operations for road haulage and sea transportation. In the meantime the results of the simulations presented in the paper support the idea of deploying ITS through wireless vehicular networks such as DSRC to enable the continuous monitoring of haulage vehicles in sea port facilities. This might be possible as the wireless vehicle network is capable of handling the data traffic associated to the exchange of messages between the haulage vehicles and the road side infrastructure and which can be associated to track and trace capabilities.

Future research work will have to consider costs, as they are an important issue when it comes to evaluate the deployment of wireless networks. Karnik and Passerini (2005) acknowledge that corporations have been found to consider wireless installations based on the lower total cost of ownership (TCO) and return on investment (ROI) scenarios. They also highlight that immediate benefits also include data accuracy and increases in user productivity. In the case presented in this paper, the elimination of costly penalties associated to delays in vessel departures or mistakes associated to incorrect billing of customers are key incentives for the deployment of ITS through wireless vehicular networks. Also we consider that the government sponsorship will be fundamental to the wide deployment of ITS/wireless vehicular networks outside road safety applications.

## 7. Conclusions

In the near future wireless vehicular networks promise to have a major impact on how transportation and logistics operations are run. In order to achieve the role and contribution of ITS the identification of information and material flows through mapping is an important step towards defining a methodology to implement wireless vehicular networks—DSRC. The role and contribution of ITS through wireless vehicular networks may include the capability to provide instant real-time tracking and tracing, which can reveal if goods are delivered/collected to/from the right place, as well as real-time updates to corporate information systems, increased security, theft prevention, increased vehicle utilisation, driver/operator monitoring, etc. representing a change of paradigm on how the supply chain can be managed. Data traffic is key to support all of the above. A large scale deployment of ITS through wireless vehicular networks such as DSRC would allow ubiquitous access to information. However, prior to large scale deployments taking place, testbeds will have to be deployed to run a number of trials and to know what sort of results will be achieved. In the particular case of wireless vehicular networks such as DSRC, a challenging scenario to deploy a test bed is represented by multimodal logistics comprising road and sea transport. The same methodology used in the analysis of bulk materials can be applied to other operations involving Ro–Ro and containers as well as bulk liquids.

To consider ITS through wireless vehicular networks such as DSRC in tipping operations as discussed in this paper is just one component of a supply chain characterised by high volumes and long lead times. However, the same technology has the potential to impact other types of supply chains such as those with low volumes and short lead times, which demand even higher levels of visibility. An example can be the handling of hazardous materials. In this research, the use of simulation represents an appropriate method to identify the capability of a wireless vehicular network to support real-time data traffic related to the exchange of messages, which are representative of the flow of events taking place in sea port multimodal logistics. The data traffic can be related to the schema containing date, contract, day, operations, destination, time, tonnage move, operator identifier, road hauler id and current position. The same technology can also be applied to other multimodal operations such as handling of containers and Ro–Ro.

The adoption of mobile communications in IP based networks can have a major impact on improving the efficiency of multimodal logistics operations especially at a time where government agencies are engaged in launching initiatives that will contribute towards efficient freight transportation and better use of resources. In recent years and as part of their own ITS initiatives, the US, Japan and Europe have emphasised the future adoption and deployment of emerging wireless vehicular technology such as DSRC to enable vehicle integration with the possibility of achieving significant reduction in road congestion, traffic accidents and vehicle wear.

Although the deployment of technologies such as Global Positioning Systems (GPS), cellular networks and Wi-Fi among others have had a significant impact on track and trace capabilities, the fact is that multimodal transport needs still can benefit from ITS through wireless vehicular networks such as DSRC for efficient operations. DSRC can become the infrastructure where data are exchanged between interested parties and hence, play a part in the definition of the role and contribution to ITS in logistics.

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## References


Akaiwa, Y., 1997. Introduction to Digital Mobile Communication. John Wiley & Sons, New York 1997.

Alexander, D., Ippoliti, M., 2007. Dedicated short-range communications (DSRC) the emerging market for advanced automotive safety and communications. ABIresearch, New York.

Blythe, P.T., 2005. Congestion charging: technical options for the delivery of future UK policy. Transportation Research Part A: Policy and Practice 39 (7–9), 571–587August–November, 571–587.

Cai, H., Lin, Y., 2008. A roadside ITS data bus prototype for intelligent highways. IEEE Transactions on Intelligent Transportation Systems 9 (2), 344–349.

Coronado Mondragon, A.E., Lyons, A.C., 2008. Investigating the implications of extending synchronised sequencing in automotive supply chains: the case of suppliers in the European automotive sector. International Journal of Production Research 46 (11), 2867–2888.

Coronado Mondragon, A.E., Lalwani, C.S., Coronado Mondragon, E.S., Coronado Mondragon, C.E., 2009. Facilitating multimodal logistics and enabling information systems connectivity through wireless vehicular networks. International Journal of Production Economics 122 (1), 229–240.

Council of Logistics Management, 1998. 〈http://www.clm1.org/mission.html〉, 12 February 98.

DFT (Department for Transport), 2007. Notification of a Joint Call for Tender for Motorways of the Sea Projects in the North Sea Region. 〈http://www.dft.gov.uk/162259/165226/jointcallnorthseamos2007fin1.pdf〉.

Dullaert, W., Neutens, T., Vanden Berghe, G., Vermeule, T., Vernimmen, B., Witlox, F., 2009. MamMoeT: an intelligent agent-based communication support platform for multimodal transport. Expert Systems with Applications 36 (7), 10280–10287.

ERTICO Research Project, 2007. 〈http://www.ertico.com/en/about_ertico/mission__vision/mission__vision.htm〉.

Farradyne, F.B., 2005. Vehicle Infrastructure Integration (VII), Architecture and Functional Requirements. Version 1.0. FHWA. ITS-US Department of Transportation, April.

InnovITS, 2008. Market Analysis of the Intelligent Transport Systems and Services (ITSS). UK.

Jiang, D., Delgrossi, L., 2008. IEEE 802.11p: towards an international standard for wireless access in vehicular environments. In: Proceedings of the IEEE Vehicular Technology Conference, VTC Spring 2008, May 11–14, pp. 2036–2040.

Juan, Z., Wu, J., McDonald, M., 2006. Socio-economic impact assessment of intelligent transport systems. Tsinghua Science & Technology 11 (3), 339–350.

Karnik, A., Passerini, K., 2005. Wireless network security—a discussion from a business perspective. In: Proceedings of the Wireless Telecommunications Symposium, 2005, pp. 261–267.

Kia, M., Shayan, E., Ghotb, F., 2000. The importance of information technology in port terminal operations. International Journal of Physical Distribution & Logistics Management 30 (3/4), 331–344.

Kim ,G., Kang, K., 2007. The economic evaluation of the active DSRC application for electronic toll collection system in Korea. In: Proceedings of the Proceedings of the International Conference on Telecommunications and Networking (TeNe)/ International Conference on Industrial Electronics, Technology and Automation (IETA), pp. 251–256.

Kengpol, A., Tuominen, M., 2006. A framework for group decision support systems: an application in the evaluation of information technology for logistics firms. International Journal of Production Economics 101, 159–171.

Leviäkangas, P., Haajanen, J, Alaruikka, A.M., 2007. Information service architecture for international multimodal logistic corridor. IEEE Transactions on Intelligent Transportation Systems 8 (4), 565–574.

Liu, W.G., Hu, X.P., Wang, X.Y., 2006. Mapping of logistics distribution knowledge for E-commerce in GIS. In: Proceedings of the International Conference on Management Science and Engineering, ICMSE 2006, vol. 5–7, Oct, pp. 36–40.

Mangan, J., Lalwani, C.S., Fynes, B., 2008. Port-centric logistics. The International Journal of Logistics Management 19 (1), 29–41.

Marousek, J., Andrews, S., Dorfman, M., 2008. A comparison of communications systems for VII. In: Proceedings of the 15th World Congress on Intelligent Transportation Systems, November 16–20, New York, New York, USA.

Neade, S., 2008. Portcentric Delivery Goes Back to Basics Raconteur Media. Supply Chain Management supplement of The Times, 5th November, p. 11.

Ngai, E.W.T., Lai, K.H., Cheng, T.C.E., 2008. Logistics information systems: the Hong Kong experience. International Journal of Production Economics 113 (1), 223–234.

NHTSA, 2005. DOT HS 809 859 nhtsa. Vehicle Safety Communications Project Task 3 Final Report. Identify Intelligent Vehicle Safety Applications Enabled by DSRC. March.

Nyquist, C., Bergsten, P., 2008. Secure and efficient intermodal transports—pilot project in the port of Gothenburg, Sweden. In: Proceedings of the 15th World Congress on Intelligent Transportation Systems, November 16–20, New York, USA.

OPNET, 2009. OPNET Technologies 〈http://www.opnet.com/〉.

Portcentric Point of View—Logistics, 2009. 〈http://www.portcentriclogistics.com/point.htm〉.

Parola, F., Sciomachen, A., 2005. Intermodal container flows in a port system network: analysis of possible growths via simulation models. International Journal of Production Economics 97 (1), 75–88.

Practel, 2008. Wireless Communications for ITS: Technologies and Markets. Issue II Prepared By: Practel, Inc. USA.

Roh, H-S., Lalwani, C.S., Naim, M., 2007. Modelling a port logistics process using the structures analysis and design technique. International Journal of Logistics: Research and Applications 10 (3), 283–302.

Seaman, C., 1999. Qualitative methods in empirical studies of software engineering. IEEE Transactions on Software Engineering 25 (4), 557–572.

Shanbaq, R., 2007. Port of Houston Authority Further Enhances Security Capabilities with Orsus' Situator. TMCnet.com, July 21, 2008. . 〈http://it.tmcnet.com/topics/it/articles/34654-port-houston-authority-further-enhances-security-capabilities-with.htm〉.

Stefansson, G., 2002. Business-to-business data sharing: a source for integration of supply chains. International Journal of Production Economics 75 (1–2), 135–146.

WAVE, 2005. Wireless Access in Vehicular Environments Networking Services. Draft IEEE P1609.3/D13, April.

Yin, R., 1994. Case Study Research, Design and Methods, second ed. Sage Publications, Thousand Oaks USA.

Zhou, W., 2009. RFID and item-level information visibility. European Journal of Operational Research 198 (1), 252–258.

Zomer, G., Anten, N., 2008. Vision on the crucial role of ITS for efficient and green European Logistics. In: Proceedings of the 15th World Congress on Intelligent Transportation Systems, November 16–20, New York, New York, USA.